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To Mr. F.J. Kee
Director of Research

FIBRE OPTICS COMMUNICATION SYSTEM USING DIGITAL TECHNIQUES - PROGRESS REPORT

D.E. Jones

Tests have been carried out on the digital communication aspects of the Fairchild TS - Leslie TS fibre optics communication system. Further testing is proposed.

A 5.2 km fibre optics communication system has been installed between Fairchild TS and Leslie TS with a four-fibre cable lashed to one of the overhead ground wires of 230 kV circuits C18R-C20R. This provides a bearer for a 1.544 Mbit/s digital communication link with 24 voice frequency channels. (This is compatible with the Bell T1 carrier system.) A standard Lenkurt 937-B transfer-trip communication system is also installed at both stations. This equipment will eventually be used to connect Fairchild TS to the microwave system at Leslie TS for protective relaying at Fairchild. It is not presently in use, however, and is available for testing and evaluation.

The test program is divided into three parts:

1. Evaluation of the digital equipment.

2. Long term evaluation of overall system reliability.

3. Evaluation of the effects of weather or other external factors on attenuation of the optical signal.

This report discusses the first part. The second part will be carried out by this Department over the next year, using automatic recording equipment. Part 3 will be carried out in cooperation with Canstar Communications over the next year.

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The communication system is being evaluated for three applications:

1. Protective relaying channels using Lenkurt 937-B frequency-shift equipment.

2. Low speed data transmission; 4.8, 7.2 or 9.6 kbit/s, using Paradyne T-48/96 modems.

3. High Speed 1.544 Mbit/s data transmission.

Test Arrangements

Two of the optical fibres were jumpered together by an optical patch cord at Fairchild, so that an optical link of 10.4 km was formed, with both transmitting and receiving equipment at Leslie for convenient testing. Figure 1 shows a block diagram of the complete system as well as the test instrumentation used.

The Channel Bank time-division multiplexes 24 voice frequency channels (300-3000 Hz) into a 1.544 Mbit/s digital stream. The optical transmitter produces a stream of optical pulses via a LED optical transmitter. This is detected in the optical receiver by an Avalanche Photo Diode (APD). The receiver channel bank demultiplexes the stream to reproduce the 24 voice frequency channels.

Operation of the system was checked for:

1. Bit Error Rate in data transmission

2. Channel Time and clock recovery time

3. Excessive Optical Attenuation

4. Brief and prolonged interruption of the 1.544 MHz clock or of the output signal from the optical receiver (see the switch contacts on Figure 1).

5. Low supply voltage

Bit Error Rate in Data Transmission

The complete system was operated with normal attenuation, transmitting low speed data via the modems. Three data rates, 4.8, 7.2 and 9.6 kbits/s, were used with a pseudo-random bit stream of 2047 bits. Then the optical system alone was operated, transmitting high speed data at 1.544 Mbits/s with a pesudo-random bit stream of $2^{20}-1$ bits. Table I shows typical results.

TABLE I

Bit Rate	Length of Test	Bit Error Rate	Block Error* Rate
4.8 kbits/s	58 h	6×10^{-8}	2×10^{-6}
7.2 kbits/s	23 min	9×10^{-5}	2×10^{-2}
9.6 kbits/s	2 min	9×10^{-4}	3×10^{-1}
1.544 Mbits/s	106 h	8.5×10^{-12}	--

* A block consists of 10^3 bits

Channel Time and Clock Recovery Time

The overall channel time was measured by switching on a 1700 Hz sine wave at the input to one channel of the channel bank transmitter and noting the delay before it appeared at the output of the channel bank receiver. Figure 2A shows a typical result. The channel time was found to be about 230 μs.

The clock recovery time was measured by switching off the 1.544 MHz clock in the channel bank transmitter and noting the delay in reappearance of the transfer trip signal when it was switched on again. This is shown in Figure 2B. The recovery time was found to be about 13 ms. This compares well with the manufacturer's claim that "a unique receiver framer reframes in 11 ms or less". The extra 2 ms may be required for clock recovery in the optical receiver.

Effect of Excessive Optical Attenuation

Table II gives the predicted optical losses, as prepared by the manufacturer. This shows an end-to-end loss of 29.6 dB (item 25). With a predicted receiver sensitivity of -61 dBm (item 16), a margin of 13.4 dB (item 26) was anticipated. Based on this, it was expected that the operation of a looped-back system might not be possible. Tests carried out during commissioning, however, showed the losses to be somewhat less:

Fibre No 1 - 15.5 dB
Fibre No 2 - 19.1 dB
Fibre No 3 - 17.0 dB
Fibre No 4 - 22.1 dB

It was found that when fibres No 1 and No 3 were interconnected for a looped-back optical link, there was about 3 dB margin at

the receiver for a bit error rate better than 10^{-9}. This was considered to be satisfactory for the proposed evaluation.

In order to determine how the system performs with increased attenuation, an optical attenuator provided by Canstar Communications was connected between the optical transmitter and receiver in place of the optical fibres[1]. Detector signal level was monitored ("DET" test point on the optical receiver) as attenuation was increased. Figure 3 shows the results. Figure 4 shows the increase in bit error rate when attenuation is increased for 1.544 Mbit/s data and 4.8 kbit/s data. Figure 5 shows the fail-to-trip probability of the 937-B equipment with increasing attenuation.

Figures 4 and 5 present important information concerning the reliability of transfer-trip signals sent through the digital fibre-optics system. The BER alarm operates at about 32.5 dB. The 937-B alarm and consequent protective relay blocking occurs at about 34 dB. At 32.5 dB the fail-to-trip probability is about 10^{-4}. Therefore, operation of the BER alarm on the optical receiver provides an indication that the transfer-trip channel is approaching a point where its reliability may be questionable.

Effect of Channel Failures

By use of a synchronous switch, the signal in the communication channel was disabled for controlled lengths of time. The time of recovery of the end device, the data receiver or the 937-B receiver output, was then measured. Clock failure and optical receiver failure were simulated, using the two switches shown in Figure 1. Tables III and IV and Figures 6 and 7 show typical results[2].

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1 Unfortunately an optical power meter was not available at the time of these tests. Therefore, no absolute values can be placed on the numbers given in this section of the report. It is proposed, however, to calibrate the system in the near future. At that time an addendum to this report will be issued giving results in terms of received optical power.

2 Ignore the slow rise time of the relay response on Figure 6. This was a function of our measuring circuit. Relay operation occurred at the beginning of the rise.

For clock failures shorter than 10 ms, the transfer trip receiver continues to function. For clock failures a bit longer than this, a coincident trip may be delayed about 40 ms. For a prolonged clock failure a coincident trip will be delayed about 500 ms after the failure is cleared. For failures of the received digital data stream, even a very short failure will cause a coincident trip to be delayed about 40 ms. This should present no problem, since coincident communication system and power system failures will not normally occur unless the power fault somehow affects the optical path.

For data transmission at 4.8kbit/s via the modems, a clock failure of 10 ms causes block error failures for 70 to 200 ms. For a prolonged clock failure, the data signal recovers from 20 to 90 ms after the clock returns. For optical receiver failure, a brief failure will cause block errors for 65 to 370 ms, whereas the data recovery after a prolonged failure may be 300-1300 ms. Much of this delay may be the time taken for the receiving modem to resynchronize.

If the signal to the channel bank receiver fails for more than 2 seconds, the output is automatically blocked for 12 seconds after the signal returns. (See Section IV, paragraph 2.06 of the Lynch Technical Manual). It is suggested that the manufacturer be requested to modify the equipment to eliminate this delay.

Effect of Low Supply Voltage

The digital and optical systems operate from the 48 V station battery. This may at times fall to 44 V. The complete system was found to operate satisfactorily at this voltage; that is the 937-B operated and the bit-error-rate in the low speed data channel gave no errors in 10^6 bits. At voltages below 44 V the channel bank failed. The optical transmitter and receiver, however, operated satisfactorily at 42 V.

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CANSTAR COMMUNICATIONS

TABLE II

FIBER OPTIC TRANSMISSION SYSTEM LINK LOSS ANALYSIS WORKSHEET

CUSTOMER/SYSTEM: ONTARIO HYDRO

PROJECT ID/QUOTATION: Q256 ENGINEER: Mestechkin DATE: July 9, 1982

LINK DESCRIPTION: FAIRCHILD TS - LESLIE TS

SYSTEM DATA	1.	LINK LENGTH ..... km	5.2
	2.	REQUIRED BANDWIDTH OR BIT RATE .. ☐ MHz ☒ Mb/s	1.5
	3.	REQUIRED SNR OR BER ..... ☐ dB ☒ BER	10^{-9}
	4.	UNIT CABLE LENGTH..... km	<2
	5.	INSTALLATION: AERIAL 4.6 km ;DUCT 0.8 km ;BURIED	-
	6.	TEMPERATURE RANGE: AERIAL -40 to +60 °C;DUCT -10 to +20 °C;BURIED	-
	7.	FIBER TYPE	MULTI MODE GRADED INDEX
	8.	OPERATING WAVELENGTH ..... nm	850
	9.	CABLE ATTENUATION ..... dB/km	4.0
	10.	ACTUAL LINK BANDWIDTH AT 200 MHz.km $^{\gamma}$ (γ = 0.8) MHz	54
	11.	NO. OF CONNECTORS	2
	12.	NO. OF SPLICES . INCLUDES 2 SPLICES FOR PIGTAILS AT TERMINAL	4
	13.	SOURCE TYPE	LED
	14.	DETECTOR TYPE	APD
SYSTEM GAIN	15.	SOURCE AV. OUTPUT POWER @ 50% DUTY CYCLE & 50% MARK RATIO dBm	-18.0
	16.	RECEIVER SENSITIVITY ..... dBm	-61.0
	17.	GAIN (15-16)..... dB	43.0
SYSTEM LOSSES	18.	CABLE LOSS (1x9) ..... dB	20.8
	19.	TOTAL CONNECTOR LOSS AT 1.5 dB/CONN (x11)..... dB	3
	20.	TOTAL SPLICE LOSS AT 0.3 dB/SPLICE (x12)..... dB	1.2
	21.	PENALTY FOR BANDWIDTH LIMITATION ..... dB	N/A
	22.	ALLOWANCE FOR EQUIPMENT AGING & TEMPERATURE DEGRADATION dB	2.0
	23.	ALLOWANCE FOR CABLE TEMP. DEGRADATION AT 0.5 dB/km.... dB	2.6
	24.	OTHER: dB	N/A
	25.	TOTAL LOSSES (SUM OF ITEMS 18 thru 24) ..... dB	29.6
MARGIN	26.	UNALLOCATED LINK LOSS MARGIN ..... dB	13.4

TABLE III

EFFECT OF CHANNEL FAILURES ON 937-B RECEIVER

Type of Channel Failure	Length of Channel Failure (ms)*	937-B Transmitter Keying	Length of Alarm Relay Closure (ms)	Delay in Closing of Trip Relay at End of Failure (ms)	Photo on Figure 6
Clock	10	Guard	40-75	--	A
	1000	Guard	1470-1495	--	
	22	Trip	40-75	--	
	10	Trip	0	40-45	B
	1000	Trip	1435-1445	500-530	
Optical Receiver	4	Guard	40-70	--	C
	1000	Guard	1460-1490	--	
	15	Trip	35-75	--	
	3	Trip	0	35-42	D
	1000	Trip	1430-1460	510-530	

* The minimum duration of channel failure available from the synchronous switch was 3 to 4 ms. In two cases there was a response from the system with this minimum duration. In the other cases, however, it was necessary to go to failure durations of 10 to 30 ms to cause a system response. The failure times shown are the minimum times for a response.

TABLE IV

EFFECT OF CHANNEL FAILURES ON 4.8 k bit/s DATA TRANSMISSION

Type of Channel Failure	Length of Channel Failure (ms)	Length of Carrier Loss in Data Test Set (ms)	Length of Block Error Period in Data Test Set (ms)	Photo on Figure 7
Clock	28 10 1000	2.5-6 0 980-990	-- 70-200 1020-1090	A B
Optical Receiver	30 1000	4-11 960-990	65-370 1280-2350	C,D

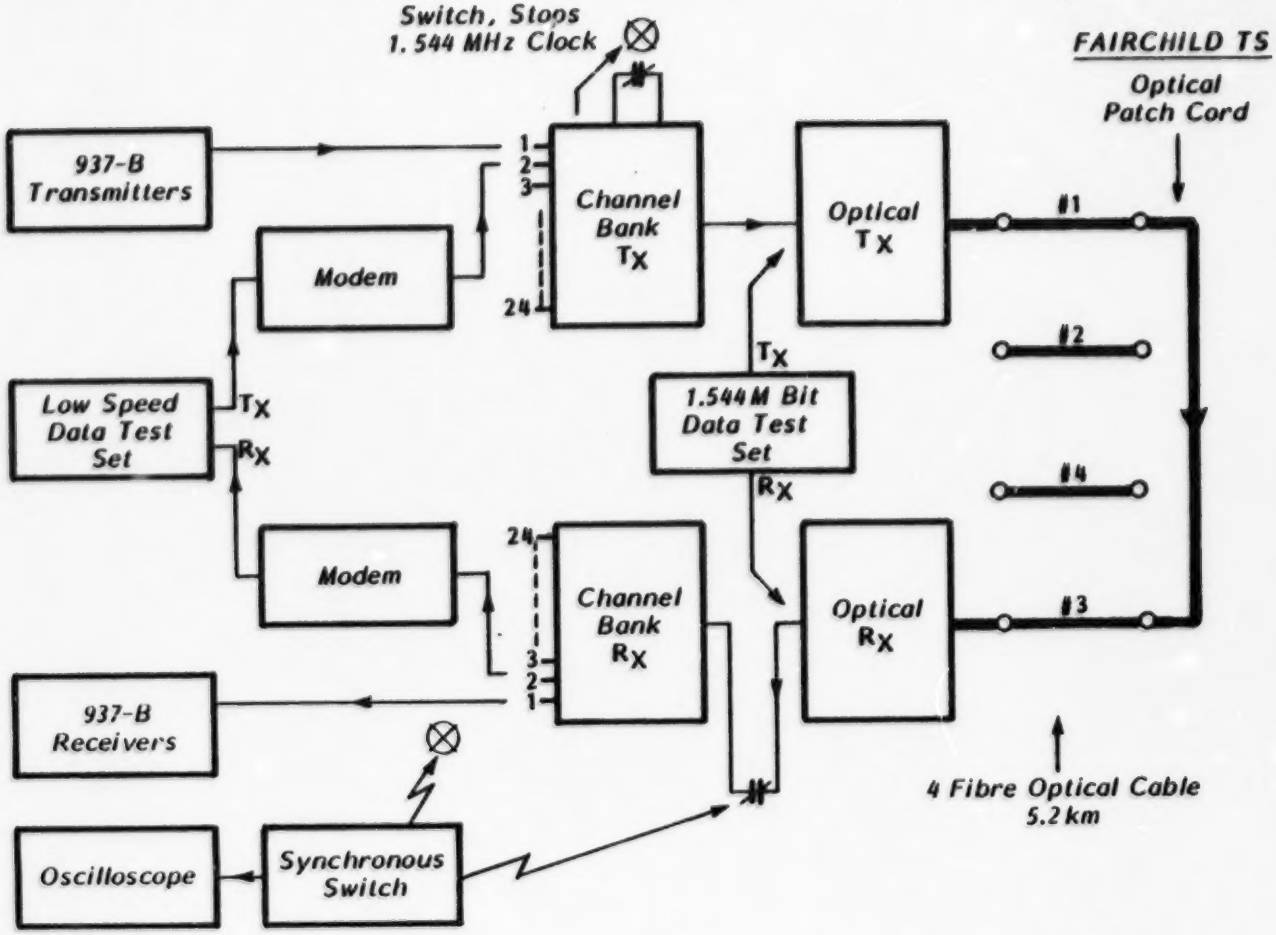
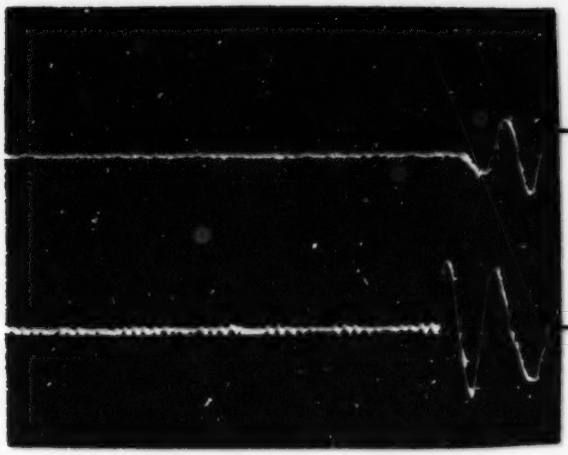


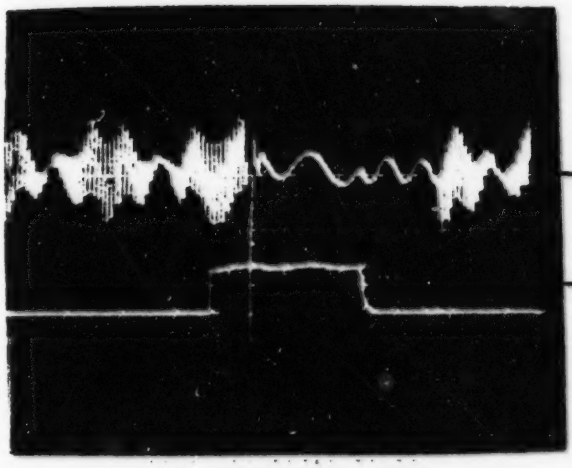
FIGURE 1

TEST ARRANAGEMENTS AT LESLIE T.S.

166912 RD



A - Channel Delay Time
Scale = 500 μs/div



B - Channel Recovery Time
Scale = 10 ms/div

FIGURE 2

166913 RD

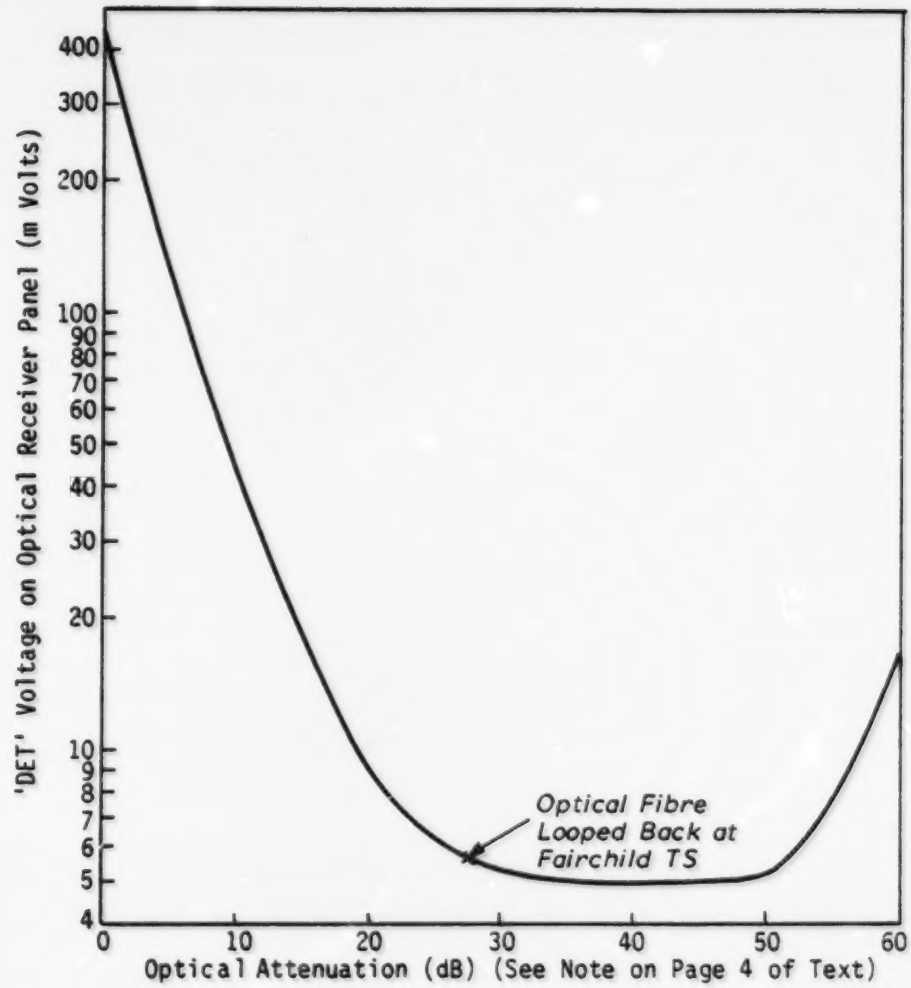


FIGURE 3

'DET' VOLTAGE ON OPTICAL RECEIVER PANEL

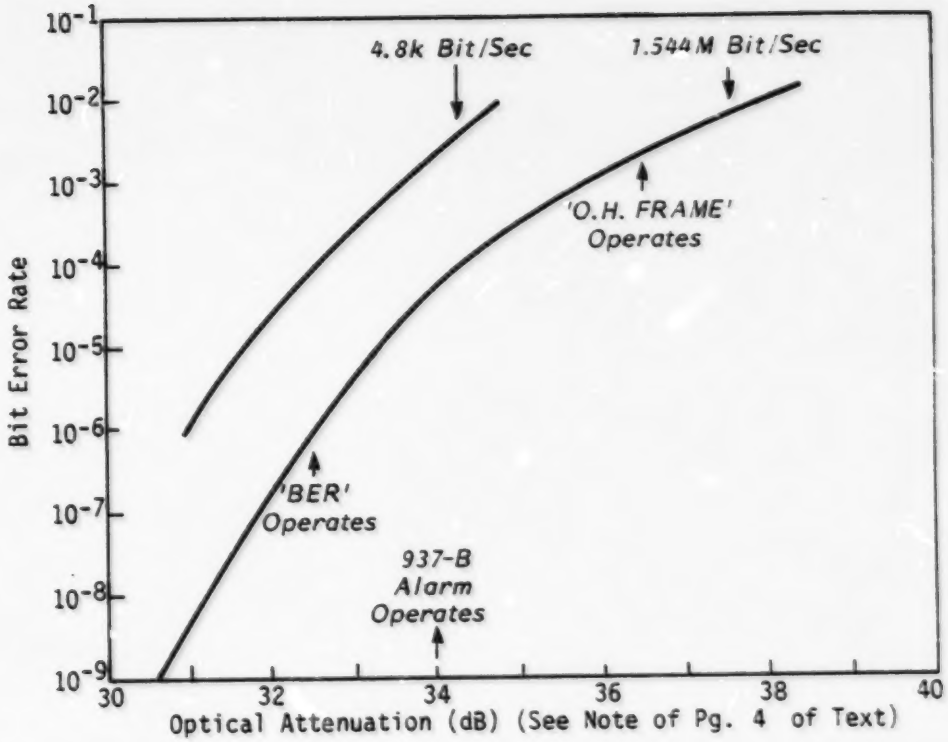


FIGURE 4

BIT ERROR RATE FOR 1.544M BIT/SEC & 4.8k BIT/SEC DATA

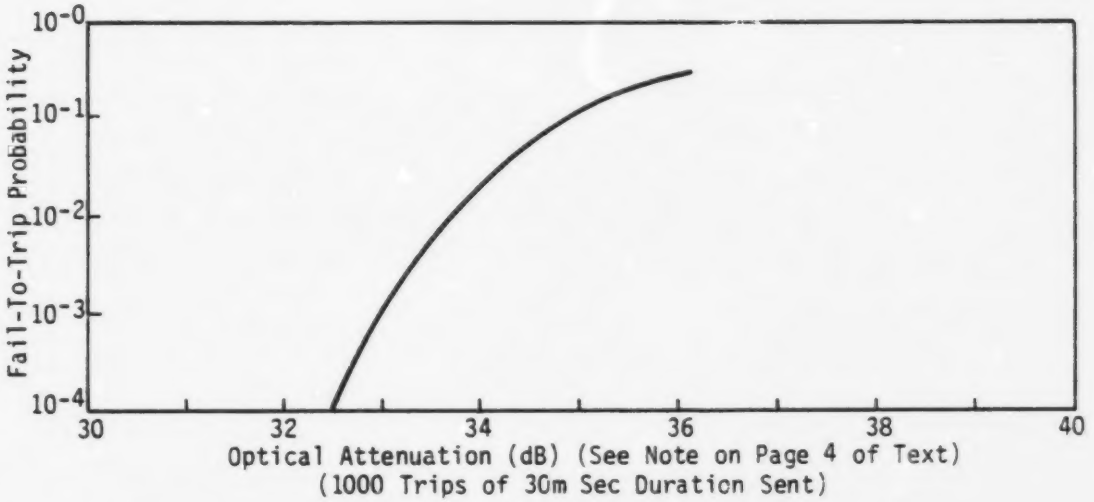


FIGURE 5

FAIL-TO-TRIP PROBABILITY OF 937-B RECEIVER

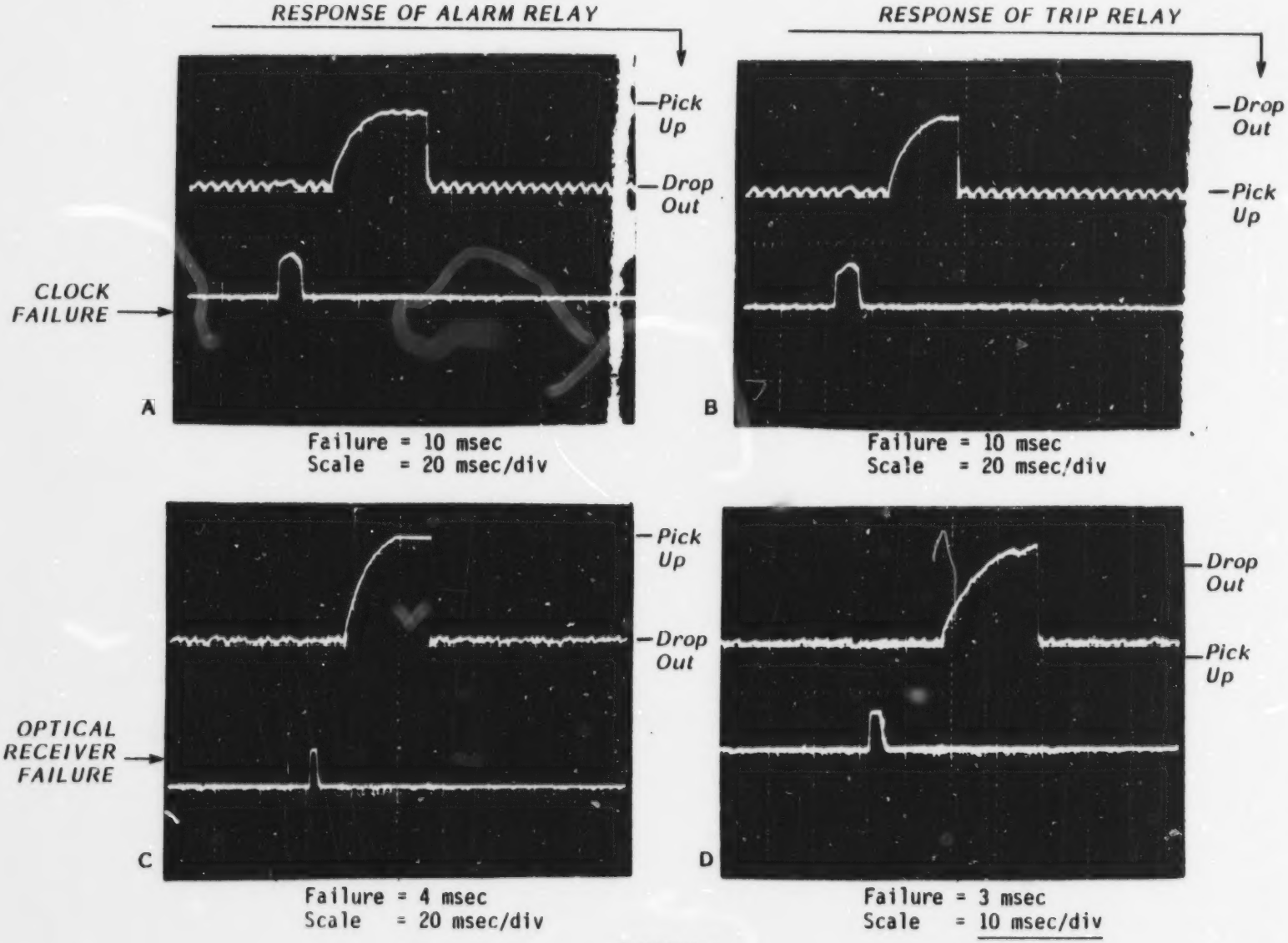


FIGURE 6

EFFECT OF BRIEF CHANNEL FAILURE ON 937-B RECEIVER

166917 RD

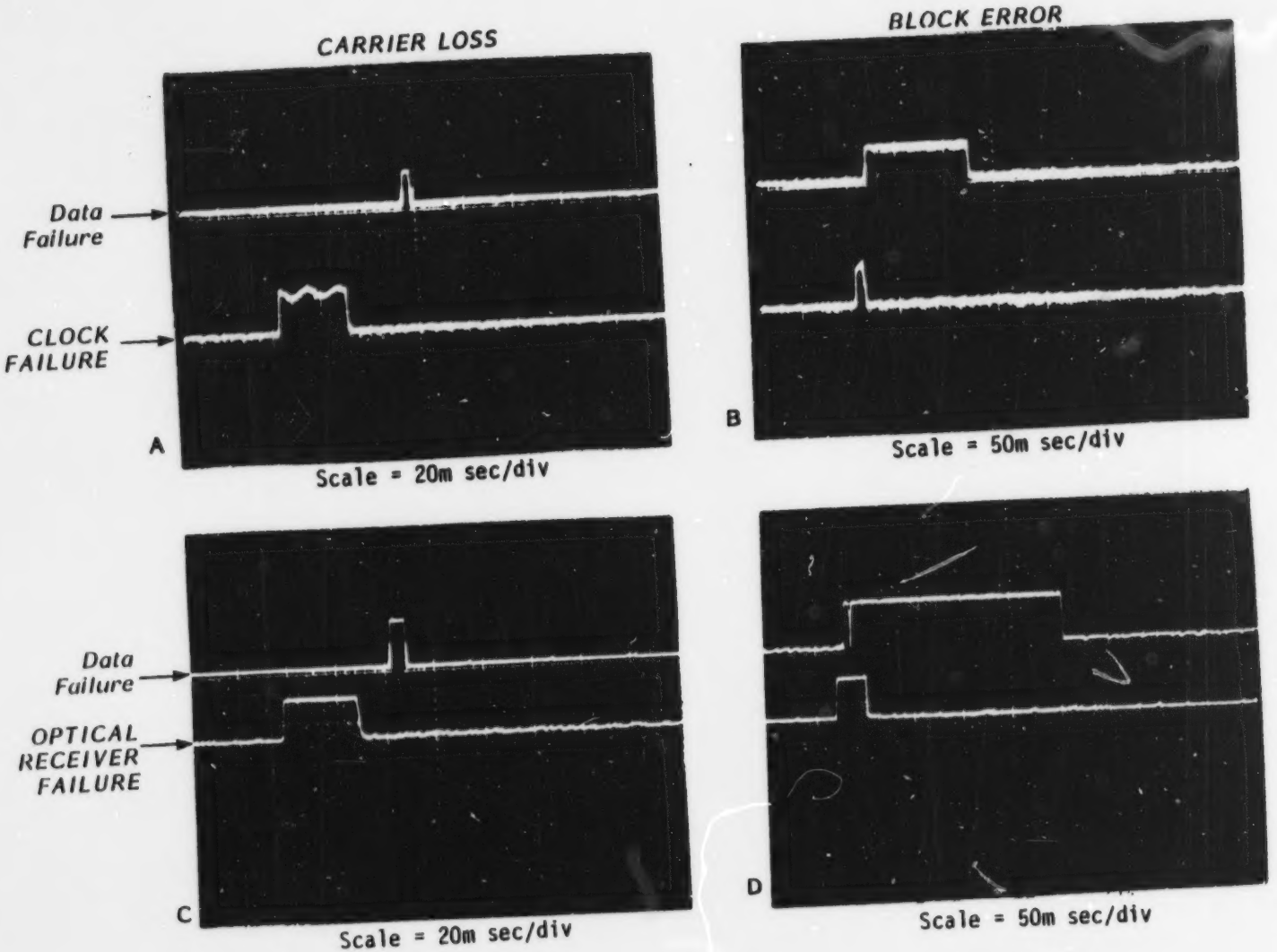


FIGURE 7

EFFECT OF BRIEF CHANNEL FAILURE ON 4.8k BIT/Sec DATA TRANSMISSION

166918 RD